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Whispering-Gallery Mode-Locked Lasers

Compact devices would generate optical pulses at repetition rates of tens of gigahertz.

NASA's Jet Propulsion Laboratory, Pasadena, California

Mode-locked lasers of a proposed type would incorporate features of the design and operation of previously demonstrated miniature electro-optical modulators and erbium-doped glass lasers that contain whispering-gallery-mode (WGM) resonators. That is to say, WGM lasers and WGM electro-optical modulators would be integrated into monolithic units that, when suitably excited with pump light and microwaves, would function as mode-locked lasers. The proposed devices are intended to satisfy an anticipated demand for compact, low-power devices that could operate in the optical-communication wavelength band centered at a wavelength of 1.55 μm and could generate pulses as short as picoseconds at repetition rates of multiple gigahertz.

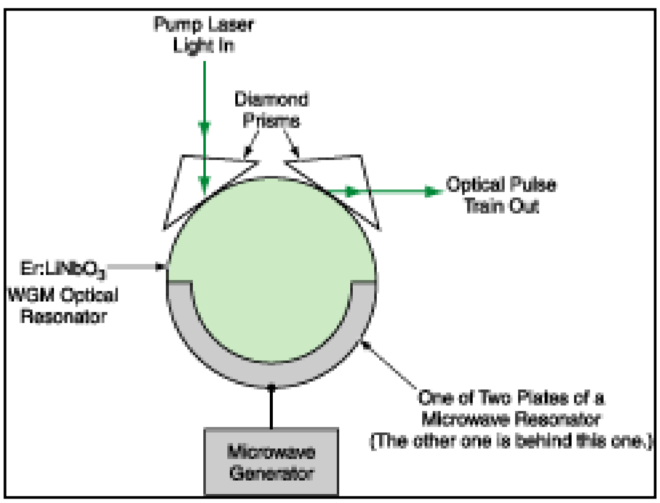
A representative device according to the proposal (see figure) would include a WGM optical resonator in the form of an oblate spheroid or disk that would have a diameter of the order of a millimeter and would be made from z-cut lithium niobate doped with erbium ($Er:LiNbO_3$). The oblateness of the spheroid or disk would be essential for suppressing undesired electromagnetic modes of the resonator. Continuous-wave (CW) pump laser light at a wavelength of 1.48 μm would be coupled into the WGM optical resonator via a diamond prism. Light would be coupled out of the optical resonator via another diamond prism. As a

result of the interaction between the pump light and the dopant erbium ions, modes at wavelengths in the vicinity of 1.54 μm would be amplified. In the absence of the design features described below, the device as described thus far would emit CW light in the 1.54-μm wavelength band.

The optical resonator would be placed between two plates of a microwave resonator. By adjusting the shape of the microwave resonator, one could adjust the frequency of resonance of the microwave field to fit the difference between the frequencies of successive modes of the optical resonator. Under this condition, the nonlinearity of dielectric response of $LiNbO_3$ would serve to couple the modes of the microwave and optical resonators.

Because of the optical/microwave coupling, the device would function as a mode-locked laser in the presence of both CW pump light and CW microwave radiation. The net result of the interaction would be the generation of pulses of light in the WGM optical resonator. Because the optical amplification would not be sensitive to phase, pulses are expected to travel circumferentially around the resonator in both directions. Hence, for example, it should be possible to extract an optical pulse train propagating in the circumferential direction opposite of that of the pump light, as shown in the figure.

The performance of the device has been estimated theoretically on the basis of the underlying physical principles and the performances of prior WGM electro-optical modulators and erbium-doped glass lasers: Pulse durations as short as several picoseconds and pulse-repetition rates of tens of gigahertz should be readily achievable, and it may be possible to reach repetition rates as high as 100 GHz. The required microwave power is expected to be no more than a few milliwatts. The pump power is expected to range from a threshold value as low as several microwatts to a maximum value high enough to yield the CW equivalent of several milliwatts of output. With respect to pulse-repetition rates and power efficiency, the proposed device would perform better than any prior device designed to satisfy the same requirements.



A **Whispering-Gallery Mode-Locked Laser** would include a WGM optical resonator made of an optically nonlinear material placed between plates of a microwave resonator so that the microwave and optical resonators would also function as an electro-optical modulator that would couple the microwave and optical fields

This work was done by Andrey Matsko, Vladimir Iltchenko, Anatoly Savchenkov, and Lute Maleki of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* **free on-line at www.techbriefs.com/tsp** *under the Physical Sciences category.*

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